

# Cooperative Work Environment Using Virtual Workspace

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## ABSTRACT

A virtual environment, which is created by computer graphics and an appropriate user interface, can be used in many application fields, such as teleoperation, telecommunication and real time simulation. Furthermore, if this environment could be shared by multiple users, there would be more potential applications.

Discussed in this paper is a case study of building a prototype of a cooperative work environment using a virtual environment, where more than two people can solve problems cooperatively, including design strategies and implementing issues. An environment where two operators can directly grasp, move or release stereoscopic computer graphics images by hand is implemented. The system is built by combining head position tracking stereoscopic displays, hand gesture input devices and graphics workstations.

Our design goal is to utilize this type of interface for a future teleconferencing system. In order to provide good interactivity for users, we discuss potential bottlenecks and their solutions. The system allows two users to share a virtual environment and to organize 3-D objects cooperatively.

## KEYWORDS

Virtual reality, virtual environment, cooperative workspace, shared workspace.

## INTRODUCTION

“Teleconferencing with realistic sensation” aims at allowing smooth and intricate communications among users by reproducing various aspects of face to face conferencing. One method for achieving this is a virtual conferencing room created by virtual reality technology. Moreover, if we

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regard this virtual conferencing room as a shared workspace among users, an environment can be formed where users can cooperatively solve various problems.

There are many studies related to virtual reality technology. Beaton et al. evaluated several input devices for a 3-D workstation[1]. They also made a comparison of graphical tasks on stereoscopic and non-stereoscopic displays. Takemura et al. evaluated a 3-D cursor locating task using several types of input devices[13,14]. It is also reported that a 3-D cursor locating task follows Fitts' Law[2,3] when a 3-D digitizer is used for cursor control. Milgram et al. compared effectiveness of depth perception on a stereoscopic display and on a display with motion parallax[10]. Hirose et al. evaluated remote operation of a hand manipulator with remote stereoscopic camera visual feedback[5]. Tachi et al. proposed design strategies for a stereoscopic TV system for teleoperation and evaluated their system[12]. Fisher et al. built a prototype system of virtual reality for telerobotics application[4]. Sturman et al. studied the possibilities of using a hand gesture in an interactive environment[11]. Codella et al. implemented a demonstration system of multi-person virtual world[18].

However, there are not many reports on cooperative environments created by virtual reality. This paper describes the concept of “telecommunications with realistic sensations”, the implementation of a cooperative work environment using this concept and an empirical study of the prototype system.

## VIRTUAL SPACE TELECONFERENCING AND VIRTUAL WORKSPACE

### Virtual Space Teleconferencing

In order to achieve “Teleconferencing with realistic sensations,” the concept of virtual teleconferencing is proposed. As shown in Figure 1, a “virtual teleconferencing” system creates an image of a conference room (virtual conference room) using computer graphics in real time. It also constructs images of the remotely located conference participants. Users of the system can talk to each other or proceed with the conference with the sensation of sharing the same space. There are many problems to be solved

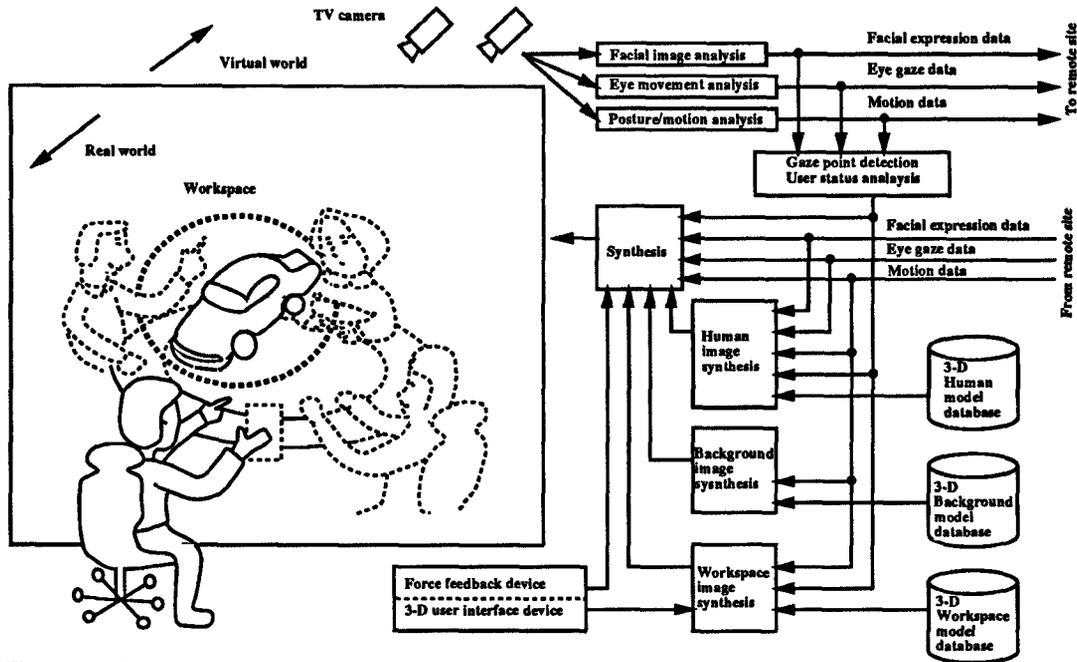


Figure 1. Virtual Space Teleconferencing

however, before this system can be realized. Some of them are now being studied at our laboratories.

A virtual workspace for virtual teleconferencing is to be generated by computer graphics. "Virtual manipulation" is a facility enabling users to interact with the virtual environment. Users can cooperatively work on tasks such as city planning or modeling a new car. In such a case, it is desired that users be able to handle objects in a virtual environment just as they do in a real environment without a sense of incompatibility. If this can be achieved, users can collaborate in various ways without any prior training of teleconferencing operations.

Figure 2(a) shows an overview of "Virtual Manipulation." First, the user's viewing position, hand position and hand

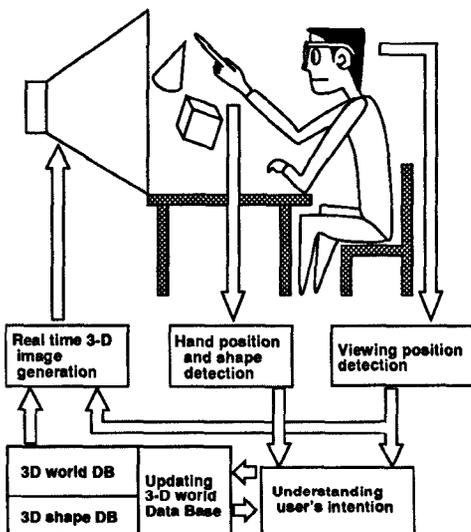


Figure 2. Virtual manipulation concept

shape are measured. The user's intentions are then analyzed to allow grasping, translating or releasing of an object in the virtual environment. The system will be able to select the object of the user's interest with higher order analysis of the user's intention. A prototype system was built for studying feasibility and usability[15].

#### Virtual Manipulation

Figure 2(b) shows the prototype systems's configuration. A 70-inch CRT projector is used as an image output device for "viewing position tracking stereoscopic display", which is a system for measuring user eye position and generating perspective projection images based on real time measurement.

User eye position is derived from the position of a 6-D magnetic sensor[9] attached to LCD shutter glasses for stereo viewing. Accordingly, the system can present non-distorted images with depth sensations and motion parallax. The screen works as a window into the virtual environment. The

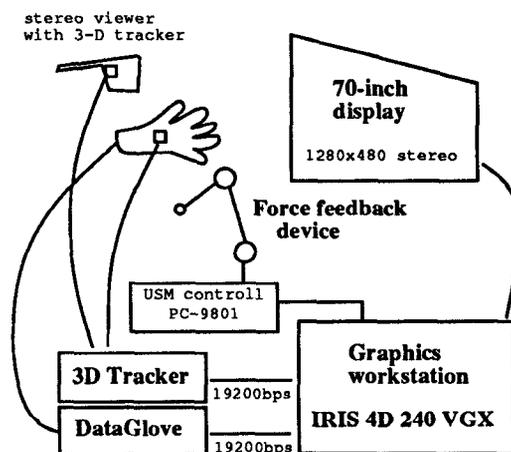


Figure 3. System overview

inside of a quadrangular pyramid determined by the screen corners and the user's eye is the space where virtual objects can be displayed stereoscopically. Viewing a 70-inch diagonal screen at a distance of 1 meter, one can have a viewing angle of 70 degrees and observe objects in an 80 cm × 60 cm rectangular area at a distance of 60 cm. This observation area is sufficiently wide in comparison with a CRT display for direct viewing. Furthermore, the image quality can easily be improved, because the size of the display system is not limited as that of HMD (head mounted display).

Currently implemented features of the system are:

- 1) Stereoscopic image generation based on the viewing position of the user;
- 2) Hierarchical object representation;
- 3) Simple gesture recognition for object handling (Table 1)
- 4) Simple simulation of physical phenomena.

A user who wears a stereo viewer and a DataGlove[17] can directly grasp the virtual object and perform such manipulation as translation and rotation. Some of the objects in the scene are fixed and some can be moved based on the constraints given to the object.

Neither the 3-D cursor nor computer graphics hand is displayed. The operation, locating one's hand where the object is perceived and grasping it, determines the target of the operation. In comparison with the method which uses an indirect pointer such as a cursor, this method is superior because it does not require users to learn how to operate cursor control devices and allows intuitive operation. By using this system, it is observed that one can manipulate a virtual object with only a slight sense of visual incompatibility.

A force feedback device using a 3-joint master manipulator with a "Torque Controllable Ultrasonic Motor (TOCUS)" has been developed and evaluated to improve system usability[16]. The end of the manipulator and the DataGlove are linked. When the operator grasps an object, the device is so controlled that he feels the weight of the object. This is an implementation of passive feedback. Besides an expression of weight, several types of force feedback are also being studied, as shown in Table 2.



Figure 4. Virtual manipulation system

Table 1. Gesture definition

Gesture	Meaning
Grasp	Grasp nearby
Release	Release object
Cancel	Return held object to its initial position
Gravity	Turn on/off gravity simulation
Nextview	Read new view definition file

Table 2. Force feedback type

Name	Control Strategy
Lock	Move the end of the arm to a certain 3-D location
Boundary display 1	Generate force towards surface normal direction
Boundary display 2	Force break on a surface
Area display	Vibrate the arm when the end is in the area
Weight display	Generate force corresponding to the object weight

Auditory or visual feedback, such as operation-related sounds or changing the objects' color, are also effective in improving the way a user interfaces with the system. Such non-contact feedback is compatible with hand shape recognition using image processing. A real time finger tip tracking system based on stereo measurement using two TV cameras is also being studied[6].

### COOPERATIVE WORK ENVIRONMENT

"Virtual manipulation" has many applications such as teleoperation, city planning, product design and man-machine interface where a small number of operators must monitor huge amounts of information, e.g., monitoring and operation of electric power plants. Providing a "virtual manipulation" environment for collaboration, the system can be used more effectively. The concept of a cooperative work environment in computer networks is known as "computer-supported cooperative work"(CSCW) or groupware. Groupware is also intended to create a shared workspace that supports dynamic collaboration in a work group over space and time constraints[7]. However, a cooperative work environment using virtual workspace is more flexible than the traditional CSCW environment which is based on conventional user interface devices, such as mice, keyboards or CRT displays.

### Prototype System

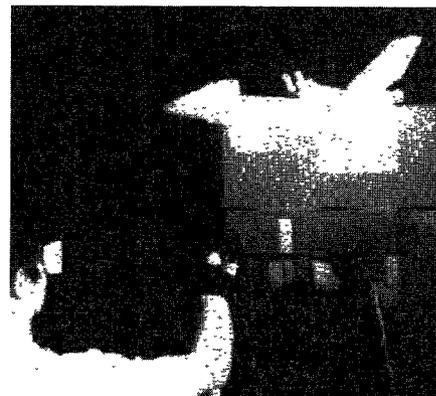


Figure 5. Force feedback user interface

Two of the systems in Figure 2 were used to implement a cooperative work environment. Object layout tasks, such as toy block layout, office furniture layout, and city building layout, were chosen as a model task to be performed in this environment. It is known that understanding the final image of a layout from a 2-D plan requires plan reading skill. From this point of view, such tasks are better suited for a 3-D virtual workspace.

Figure 6 shows the system configuration. Data communication was carried out using a local area network and auditory communication by means of an in-house telephone network.

Figure 7 shows the system processing diagram. A "3D Shape Data Base" is installed at each site for faster computer graphics(CG) image generation, as is a copy of the "Virtual World Data Base." Only retrieval is allowed with the "3D Shape Data Base." CG images are locally generated based on the user's head position data (HPD), "3D Shape Data Base" and "Virtual World Data Base." HPD and "hand shape data"(HSD) are also transmitted to the other site and the "Virtual World Data Base Manager" (VWDBM). VWDBM updates the "Virtual World Data Base" according to incoming data and predefined hand gestures. The updated portion of the data base is then distributed to each site. The sites communicate with each other via a TCP/IP socket connection.

This implementation structure has the following characteristics:

- 1)Each site can rapidly generate a CG image, because a copy of the data for the image generation is distributed to each site.
- 2)Gesture understanding and data base updating are performed only by VWDBM. Therefore, it is relatively easy to implement a mutual exclusion facility, such as prohibiting two users from simultaneously grasping the same object.
- 3)Once the "3D Shape Data Base" and "Virtual World Data Base" are distributed to each site, there is relatively

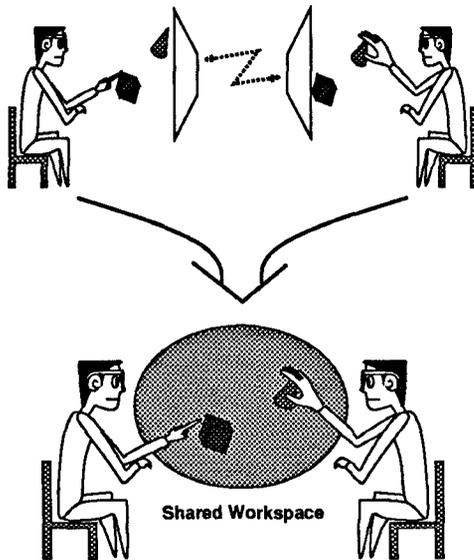


Figure 6. Shared workspace configuration

little data traffic.

However, the communication link between the two sites is subject to a transmission delay and results in a delay in the user's getting results of their operation.

### Implementation Issues

In this section, system implementation issues are described, as follows.

**Consistency** Each site must share the status of a virtual world, which changes according to operations performed at multiple sites. Therefore, there must be a mechanism to maintain consistency.

The simplest way to maintain consistency of a distributed virtual world database is to restrict manipulation, such that only one site can perform operations to alter the status of the virtual world at one time, such as grasping, rotating or translating an object. This mechanism can be easily implemented by token passing. A site which has a token is allowed to manipulate objects in the virtual world. When there is no need for manipulation, the token is passed to the next site. However, this mechanism obviously narrows the possibility of cooperative work. When N sites are used, a single site is the source of actual operation and the other N-1 sites present the results of operation.

Another way to solve this problem is assuming that an operation on one object does not interfere with an operation on another object. By making this assumption, it is possible to allow N different sites to simultaneously manipulate N different objects. The results of an operations at each site are collected at the master site and then redistributed to all sites. In our prototype system, this method is used.

**Mutual exclusion** If users simultaneously try to alter the status of a virtual world, the status may end up contradictory. For example, two users may simultaneously try to grasp the same object and translate it in different directions. These operations must be prohibited to avoid inconsistency in virtual world status.

Mutual exclusion to avoid simultaneous manipulation of the

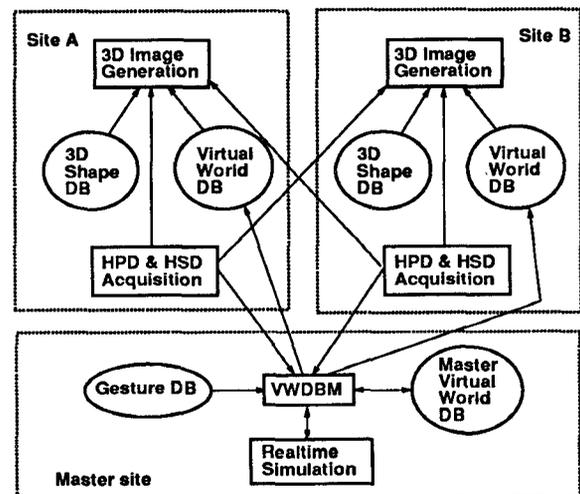


Figure 7 Processing architecture

same object must also be incorporated. If the system has a master site in which all requests for an operation are concentrated, this can be accomplished by simply giving a priority to each request. When two sites request an operation at the same time, the master site allows an operation by the site with higher priority. Objects being manipulated are marked in order to prohibit manipulation by the other site.

**Interactivity** In order to provide good interaction, the system must respond to users' reactions as quickly as possible. Unlike a single user system, interactivity in a cooperative work environment is affected by the time required for data transmission. Therefore, processing which can be performed locally must be selected and should be implemented at each local site. Distributing redundant data to each site may significantly reduce communication between two sites and improve system response. In particular, the following strategies are actually used:

1) 3-D shape data of objects in the virtual environment are distributed to each local sight. A user's head position is also measured locally. Using this head position data and

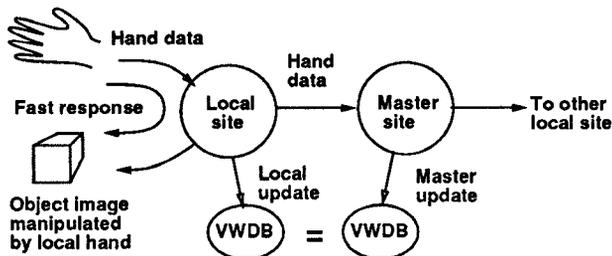


Figure 8. Local loop for fast response

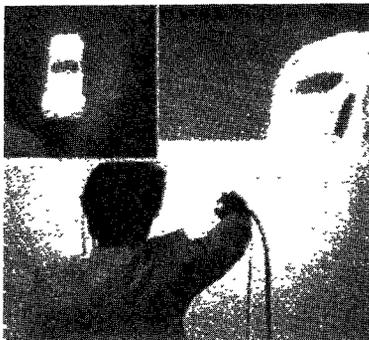


Figure 9. Opposite view orientation

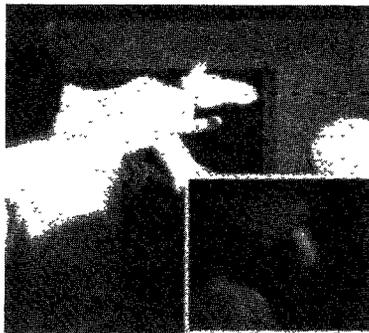


Figure 10. Common view orientation

3-D data, a 3-D scene can be rendered locally. Thus, a user at a local site has a minimum delay in image generation based on one's head position.

2) When a user grasps an object in the virtual environment, a lag between one's hand motion and object motion is minimized by locally binding one's hand position data and object position (Figure 8). At the same time, hand position data is transmitted to the master site to update the master virtual world database, the updated database of which is then distributed to other local sites. This local binding does not cause any inconsistency in the virtual world database provided that each object in the virtual world is manipulated by a single hand at any one time.

### Using The System

Figure 9 shows two users facing each other and manipulating the CG image of an automobile, located between the two users. Figure 10 shows two users looking in the same direction and sharing the same view. The users are cooperatively assembling a horse-shape 3-D puzzle. In this case, the configuration of looking in the same direction enables the users to share more visual information.

When the opposite view configuration is used, work space which can be shared, is limited as shown in Figure 11(a). The area marked S can be accessed by both users. The area marked E can be viewed by only either of them. Neither of them can perform operations in area E because it is behind the screen. This configuration is useful provided that the task performed requires observation of objects from different points of view. For example, office furniture layout requires an evaluation of the layout from various points of view and is very suitable for this configuration.

On the other hand, when two users are facing in the same direction, the background, which is marked B in Figure 11(b) is also shared by the two users. This configuration also enables them to share a view. Such view sharing is difficult in a real environment because of physical constraints. This configuration is useful for explaining, training or teaching an operation on objects, for example, teaching engine maintenance.

### Experiment

Anoperator performance during a simple object moving task was measured using the prototype system. Twenty-seven cubes were placed in a virtual workspace with cubic configuration (3 x 3 x 3) as shown in Figure 12. One surface of a cube was colored with either red or blue. The other 5

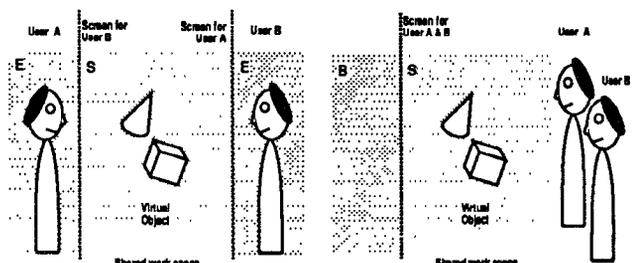


Figure 11. Shared workspace comparison

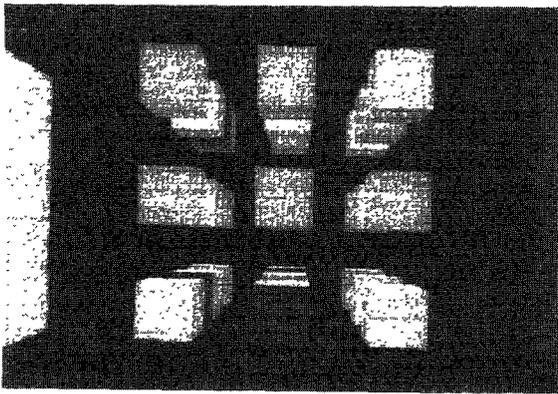


Figure 12. An example of cube layout

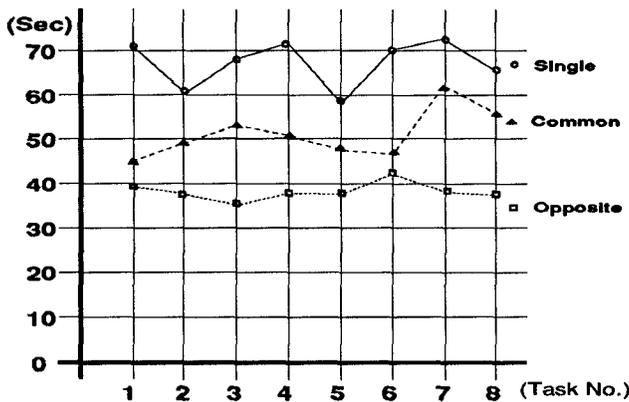


Figure 13. Task completion time comparison

surfaces of a cube were not colored. The orientation of each cube was randomly chosen between two possible orientations. One is an orientation where a colored surface faces towards a user. The other is an orientation which is opposite to the former one. The colored surface is located behind the surface which faces to a user. Therefore, the subject cannot determine color of the cube without rotating it. A subject was asked to move cubes to two specific target areas according to their color as quickly as possible. The time required for placing all (twenty-seven) cubes to the target area was measured. The system also recorded the time required for a single cube placement, which consists of grasping a cube, translating it to its target area and releasing

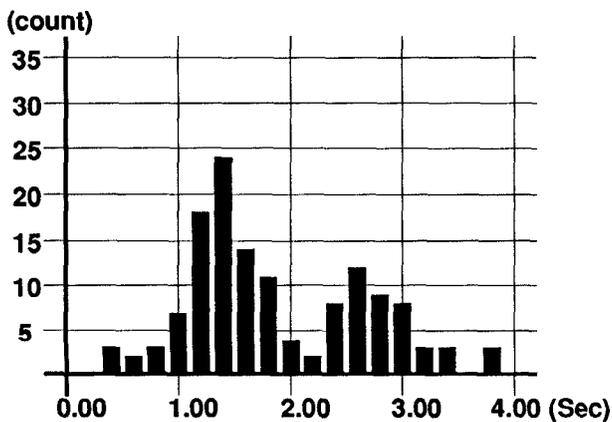


Figure 14 single cube operation with common view

it.

The task was performed eight times in three different situations, respectively. these are,

- 1) A single subject operator performed the task;
- 2) Two subject operators performed the task with common view;
- 3) Two subject operators performed the task with opposite view.

The task completion time is shown in Figure 13. Apparently, cooperative work environments have much better performance compared to a single operation. Among cooperative environments, an opposite view configuration shows significantly better performance to a common view configuration.

Figures 14 and 15 show the distribution of single cube placement performance by one operator with common view and with opposite view configuration, respectively. In case of common view, there are two peaks in the distribution. This is because cube placement tasks are divided into two different types. When colored face is visible to the operator, the cube can be directly placed to the target area. When invisible, the cube must be rotated by the operator to determine its color. The peak at 2.6 second is the latter case. In case of opposite view, each operator choose cubes for which colored the face was visible to them. Therefore, there is a single peak in Figure 15. These results show that this experimental task are suitable for opposite view configuration. Further study of simple, but component, operations are planned for usability analysis of the environment.

#### SUMMARY

The concept of "Virtual Manipulation" in "Teleconferencing with Realistic Sensations" has been described. A cooperative work environment using "Virtual Manipulation" has been proposed and its implementation issues discussed. A prototype system, where two people can solve problems cooperatively, has been implemented, tested and found to be satisfactory in object arranging tasks. Specific design criteria of the system, such as concurrency and interactivity control have also been described.

A subjective evaluation of the environment is in progress

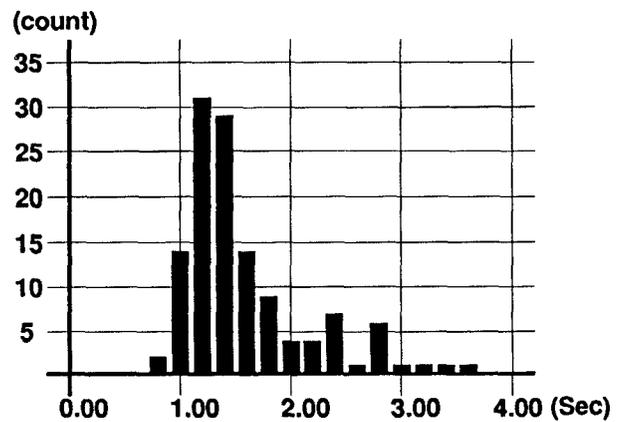


Figure 15. Single cube operation with opposite view

and will help us to understand the feasibility and ramifications of this new communication media.

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